UNIT - III

TUNED AMPLIFIERS

Introduction to tuned circuits

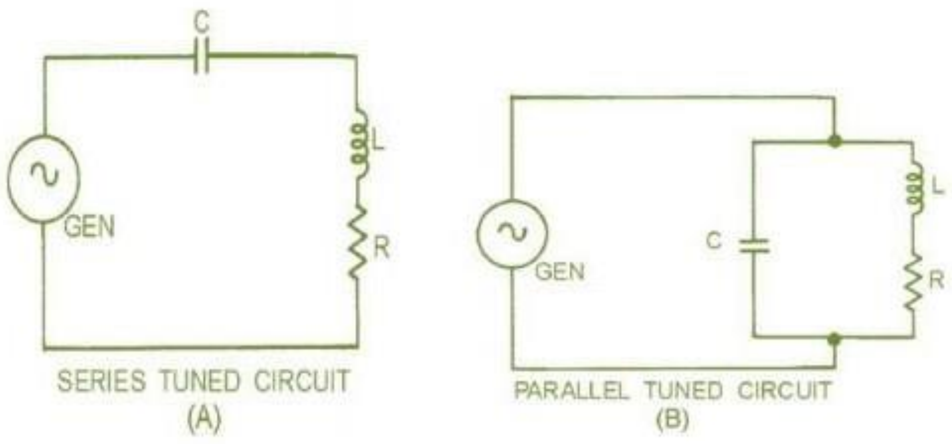
When a radio or television set is turned on, many events take place within the "receiver" before we hear the sound or see the picture being sent by the transmitting station. Many different signals reach the antenna of a radio receiver at the same time. To select a station, the listener adjusts the tuning dial on the radio receiver until the desired station is heard. Within the radio or TV receiver, the actual "selecting" of the desired signal and the rejecting of the unwanted signals are accomplished by means of a tuned circuit.

A tuned circuit consists of a coil and a capacitor connected in series or parallel. Whenever the characteristics of inductance and capacitance are found in a tuned circuit, the phenomenon as RESONANCE takes place.

Resonance circuits

The frequency applied to an LCR circuit causes XL and XC to be equal, and the circuit is RESONANT. If XL and XC are equal ONLY at one frequency (the resonant frequency). This fact is the principle that enables tuned circuits in the radio receiver to select one particular frequency and reject all others.

This is the reason why so much emphasis is placed on XL and X C . figure 1-1 Shows that a basic tuned circuit consists of a coil and a capacitor, connected either in series, view (A), or in parallel, view (B). The resistance (R) in the circuit is usually limited to the inherent resistance of the components (particularly the resistance of the coil).



[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

Tuned amplifier

✓ Communication circuit widely uses tuned amplifier and they are used in MW

& SW radio frequency 550 KHz – 16 MHz, 54 – 88 MHz, FM 88 – 108 MHz, cell phones 470 - 990 MHz

✓ Band width is 3 dB frequency interval of pass band and –30 dB frequency interval

✓ Tune amplifiers are also classified as A, B, C similar to power amplifiers based on conduction angle of devices.

Series resonant circuit

Series resonant features minimum impedance (RS) at resonant.

✓ f r = ½ √LC; q = L/Rs at resonance L=1/c, BW=fr/Q

✓ It behaves as purely resistance at resonance, capacitive below and inductive above resonance

Paralel resonant circuit

✓ Paralel resonance features maximum impedance at resonance = L/RsC

✓ At resonance Fr=1/2√1/(LC-Rs2/L2); if Rs=0, fr=1/2√(LC)

✓ At resonance it exhibits pure resistance and below fr parallel circuit exhibits inductive and above capacitive impedance

Need for tuned circuits:

To understand tuned circuits, we first have to understand the phenomenon of self-induction. And to understand this, we need to know about induction. The first discovery about the interaction between electric current and magnetism was the realization that an electric current created a magnetic field around the conductor. It was then discovered that this effect could be enhanced greatly by winding the conductor into a coil. The effect proved to be two-way: If a conductor, maybe in the form of a coil was placed in a changing magnetic field, a current could be made to flow in it; this is called induction.

So imagine a coil, and imagine that we apply a voltage to it. As current starts to flow, a magnetic field is created. But this means that our coil is in a changing magnetic field, and this induces a current in the coil. The induced current runs contrary to the applied current, effectively diminishing it. We have discovered self-induction. What happens is that the self-induction delays the build-up of current in the coil, but eventually the current will reach its maximum and stabilize at a value only determined by the ohmic resistance in the coil and the voltage applied. We now have a steady current and a steady magnetic field. During the buildup of the field, energy was supplied to the coil, where did that energy go? It went into the magnetic field, and as long as the magnetic field exists, it will be stored there.

Now imagine that we remove the current source. Without a steady current to uphold it, the magnetic field starts to disappear, but this means our coil is again in a variable field which induces a current into it. This time the current is in the direction of the applied current, delaying the decay of the current and the magnetic field till the stored energy is spent. This can give a funny effect: Since the coil **must** get rid of the stored energy, the voltage over it rises indefinitely until a current can run somewhere! This means you can get a surprising amount of sparks and arching when coils are involved. If the coil is large enough, you can actually get an electric shock from a low-voltage source like an ohmmeter.

Applications of tuned amplifier

A tuned amplifier is a type of electronic device designed to amplify specific ranges of electrical signals while ignoring or blocking others. It finds common use in devices that work with radio frequency signals such as radios, televisions, and other types of communication equipment; however, it also can be useful in many other applications. Tuned amplifiers can be found in aircraft autopilot systems, audio systems, scientific instruments, spacecraft, or anywhere else there is a need to select and amplify specific electronic signals while ignoring others.

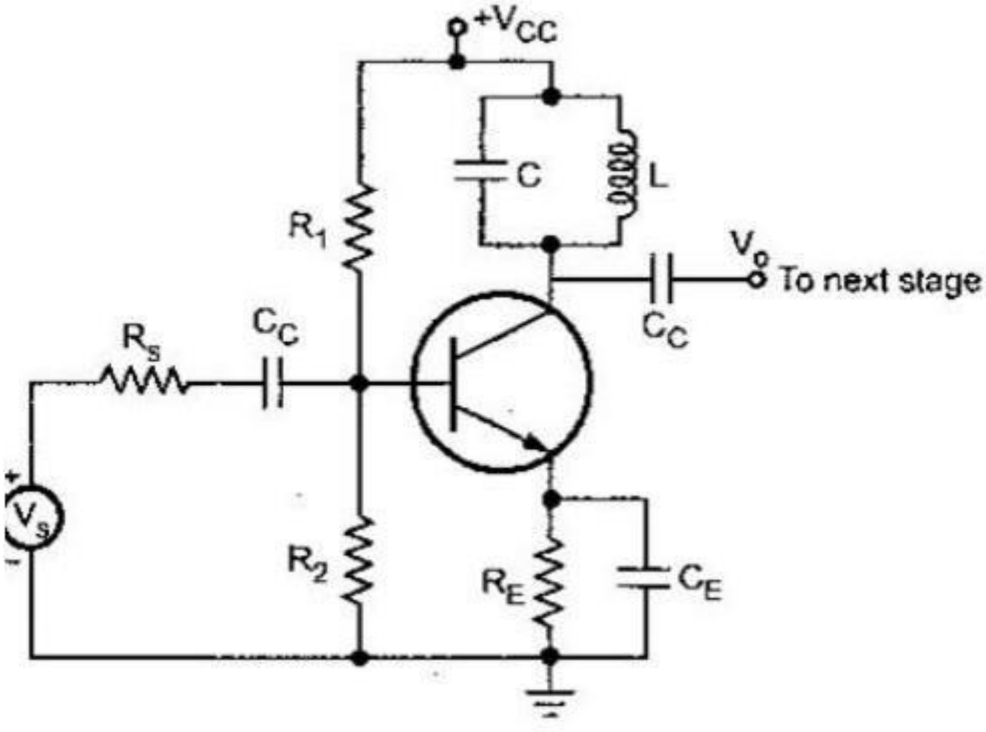
The most common tuned amplifiers an average person interacts with can be found in home or portable entertainment equipment, such as FM stereo receivers. An FM radio has a tuned amplifier that allows listening to only one radio station at a time. When the knob is turned to change the station, it adjusts a variable capacitor, inductor, or similar device inside the radio, which alters the inductive load of the tuned amplifier circuit. This retunes the amplifier to allow a different specific radio frequency to be amplified so a different radio station can be heard.

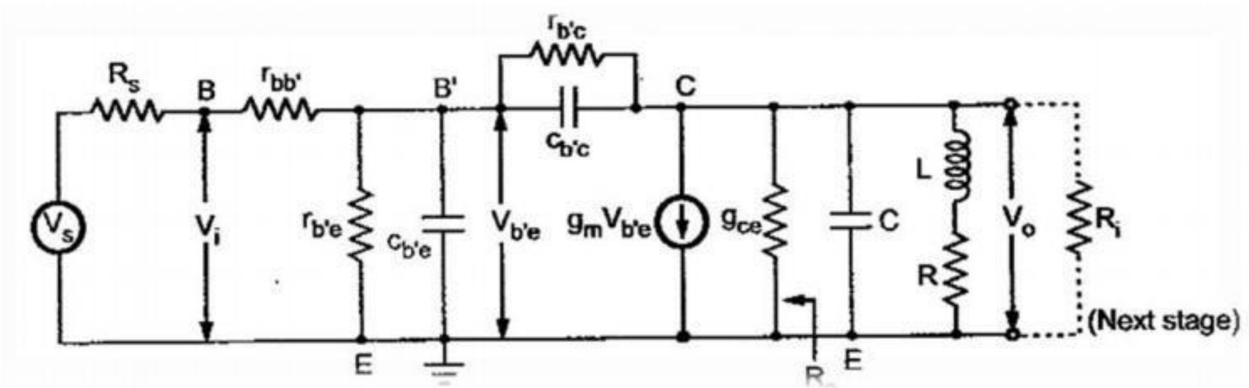
CLASSIFICATION:

1. Single tuned amplifier
2. Double tuned amplifier
3. Stagger tuned amplifier

1. Single tuned amplifier

Single Tuned Amplifiers consist of only one Tank Circuit and the amplifying frequency range is determined by it. By giving signal to its input terminal of various Frequency Ranges. The Tank Circuit on its collector delivers High Impedance on resonant Frequency, Thus the amplified signal is Completely Available on the output Terminal. And for input signals other than Resonant Frequency, the tank circuit provides lower impedance, hence most of the signals get attenuated at collector Terminal.





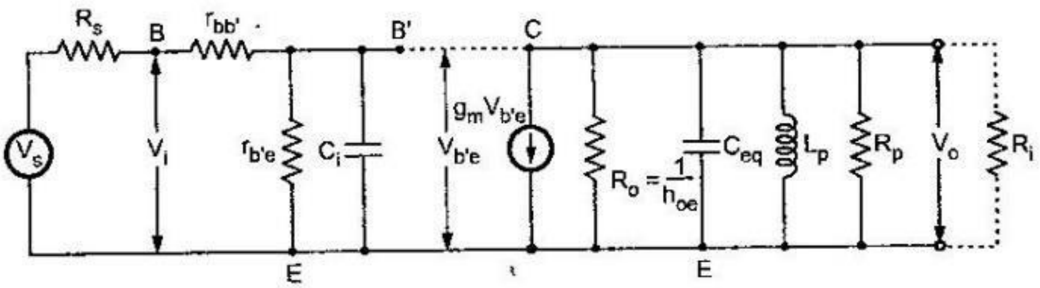
[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

R_i- input resistance of the next stage

R_0-output resistance of the generator g_mVb'e

C_c & C_E are negligible small

The equivalent circuit is simplified by



Simplified equivalent circuit

$$C_i = C_{b'e} + C_{b'c}(1 - A)$$

$$C_{eq} = C_{b'c}\left(\frac{A-1}{A}\right) + C$$

Where,

A-Voltage gain of the amplifier

C-tuned circuit capacitance

$$g_{ce} = \frac{1}{r_{ce}} = h_{oe} - g_m h_{re} \approx h_{oe} = \frac{1}{R_o}$$

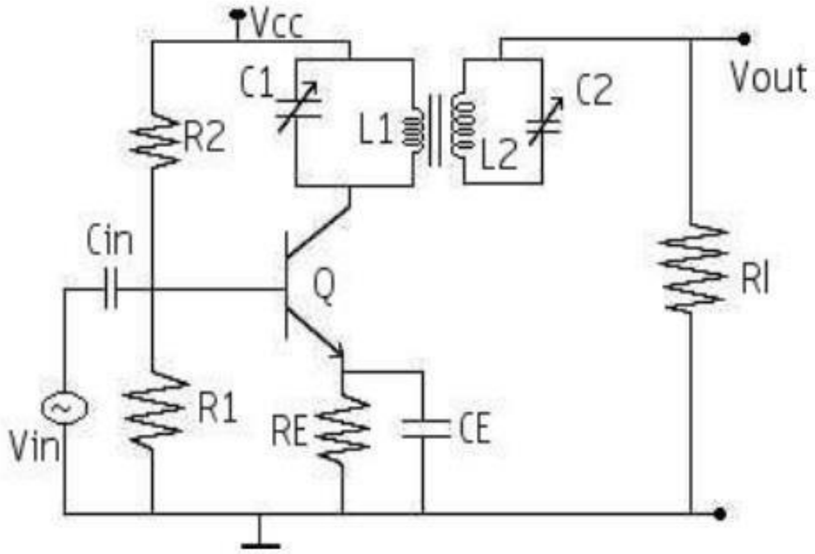
[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

Double tuned amplifier

An amplifier that uses a pair of mutually inductively coupled coils where both primary and secondary are tuned, such a circuit is known as "double tuned amplifier". Its response will provide

substantial rejection of frequencies near the pass band as well as relative flat pass band response. The disadvantage of POTENTIAL INSTABILITY in single tuned amplifiers can be overcome in Double tuned amplifiers.

A double tuned amplifier consists of inductively coupled two tuned circuits. One L1, C1 and the other L2, C2 in the Collector terminals. A change in the coupling of the two tuned circuits results in change in the shape of the Frequency response curve.



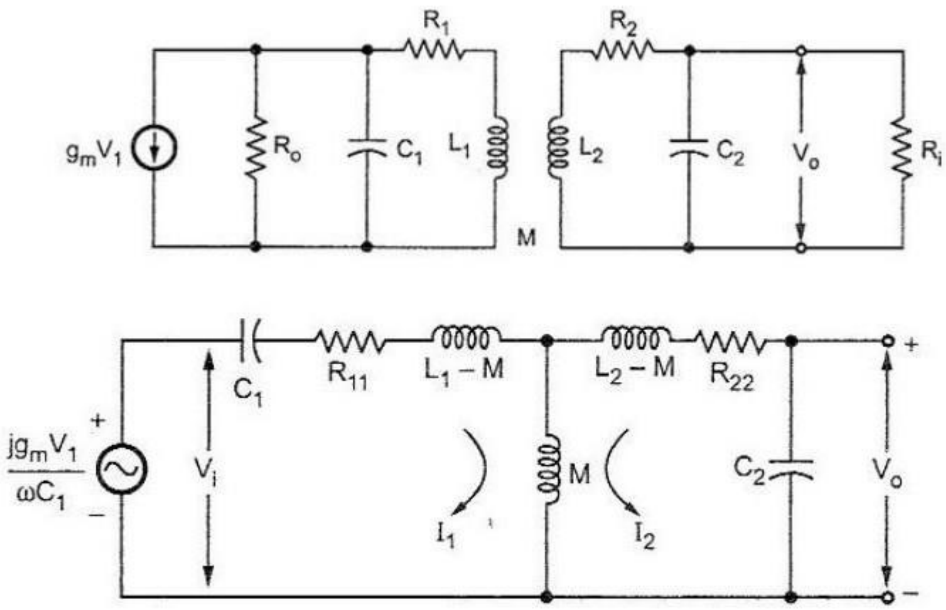
[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

By proper adjustment of the coupling between the two coils of the two tuned circuits, the required results (High selectivity, high Voltage gain and required bandwidth) may be obtained.

Operation:

The high Frequency signal to be amplified is applied to the input terminal of the amplifier. The resonant Frequency of TUNED CIRCUIT connected in the Collector circuit is made equal to signal Frequency by varying the value of C1. Now the tuned circuit L1, C1 offers very high Impedance to input signal Frequency and therefore, large output is developed across it. The output from the tuned circuit L1,C1 is transferred to the second tuned circuit L2, C2 through Mutual Induction. Hence the Frequency response in Double Tuned amplifier depends on the Magnetic Coupling of L1 and L2

Equivalent circuit of double tuned amplifier:



[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

$$\dot{Y}_T = \frac{kQ^2}{\omega_r \sqrt{L_1 L_2}\left[4Q\delta - j(1 + k^2Q^2 - 4Q^2\delta^2)\right]}$$

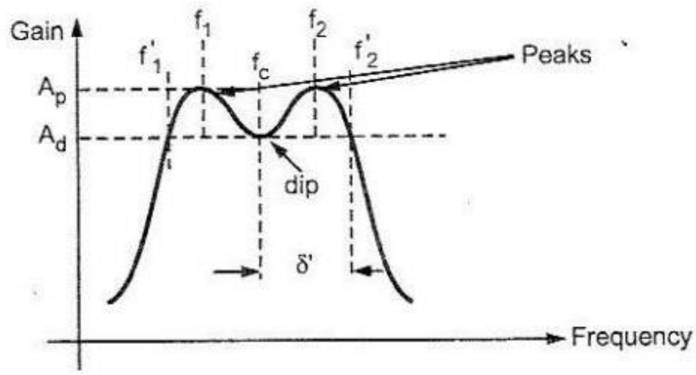
$$|A_v| = g_m \omega_r \sqrt{L_1 L_2}\, Q \frac{kQ}{\sqrt{1 + k^2Q^2 - 4Q^2\delta^2 + 16Q^2\delta^2}}$$

Two gain peaks in frequencies f_1 and f_2

$$f_1 = f_r\left(1 - \frac{1}{2Q}\sqrt{k^2Q^2 - 1}\right) \text{ and}$$

$$f_2 = f_r\left(1 + \frac{1}{2Q}\sqrt{k^2Q^2 - 1}\right)$$

This condition is known as critical coupling.



AT

$$k^2Q^2 = 1, \text{ i.e. } k = \frac{1}{Q}, f_1 = f_2 = f_r$$

For the values of $k<1/Q$ the peak gain is less than the maximum gain and the coupling is poor. For the values $k> 1/Q$, the circuit is overcoupled and the response shows double peak. This double peak is useful when more bandwidth is required

The gain magnitude at peak is given as,

$$|A_p| = \frac{g_m \omega_o \sqrt{L_1 L_2}\ kQ}{2}$$

And gain at the dip at $\delta = 0$ is given as,

$$|A_d| = |A_p| \frac{2\ kQ}{1 + k^2Q^2}$$

The ratio of peak and dip gain is denoted as γ and it represents the magnitude of the ripple in the gain curve.

$$\gamma = \left|\frac{A_p}{A_d}\right| = \frac{1 + k^2Q^2}{2\ kQ}$$

Using quadratic simplification and positive sign

$$kQ = \gamma + \sqrt{\gamma^2 - 1}$$

Bandwidth:

$$BW = 2\ \delta' = \sqrt{2}\ (f_2 - f_1)$$

At 3dB Bandwidth

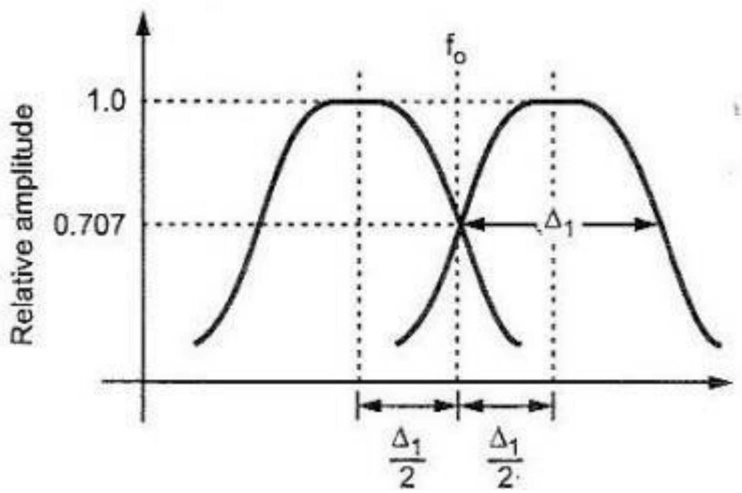
$$3\ dB\ BW = \frac{3.1\ f_r}{Q}$$

2. Staggered tuned amplifier

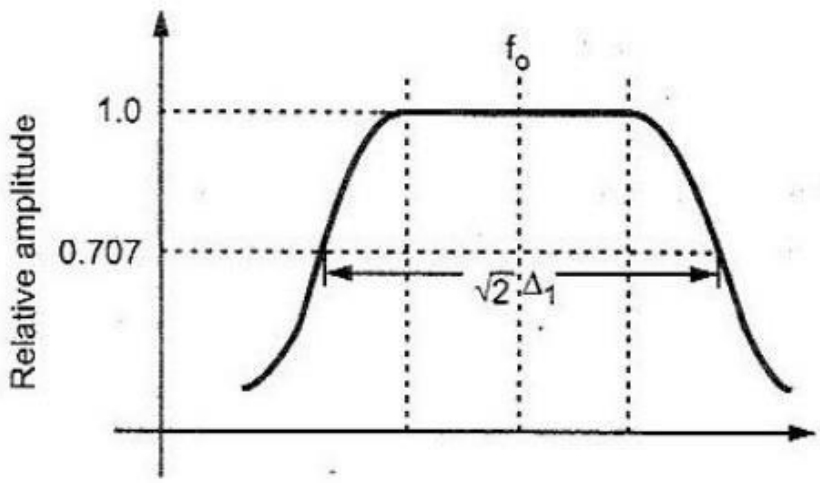
Double tuned amplifier gives greater 3 dB bandwidth having steeper sides and flat top. But alignment of double tuned amplifier is difficult.

To overcome this problem two single tuned cascaded amplifiers having certain bandwidth are taken and their resonant frequencies are so adjusted that they are separated by an amount equal to the bandwidth of each stage. Since the resonant frequencies are displaced or staggered, they are known as staggered tuned amplifiers. If it is desired to build a wide band high gain amplifier, one procedure is to use either single tuned or double tuned circuits which have been heavily loaded so as to increase the bandwidth.

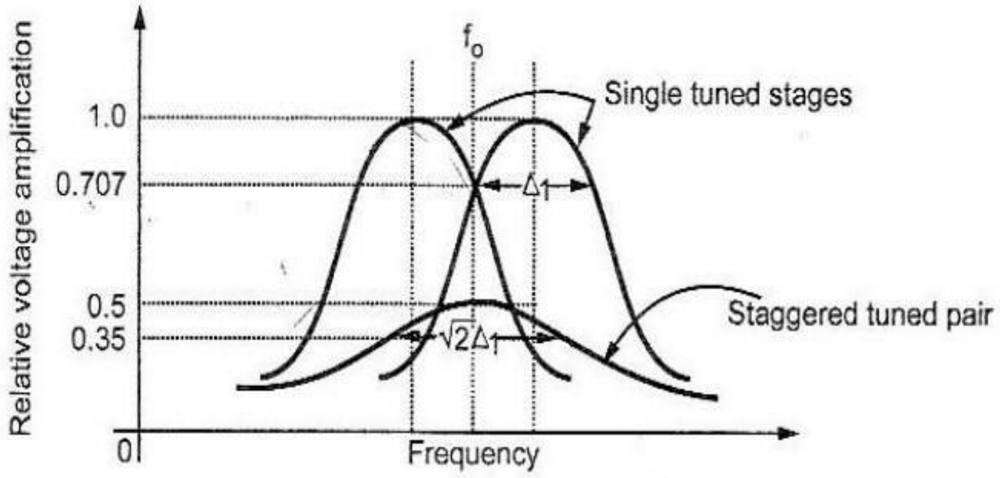
The gain per stage is correspondingly reduced, by virtue of the constant gain-bandwidth product. The use of a cascaded chain of stages will provide for the desired gain. Generally, for a specified gain and bandwidth the double tuned cascaded amplifier is preferred, since fewer tubes are often possible, and also since the pass-band characteristics of the double tuned cascaded chain are more favorable, falling more sensitive to variations in tube capacitance and coil inductance than the single tuned circuits.



Response of individual stages

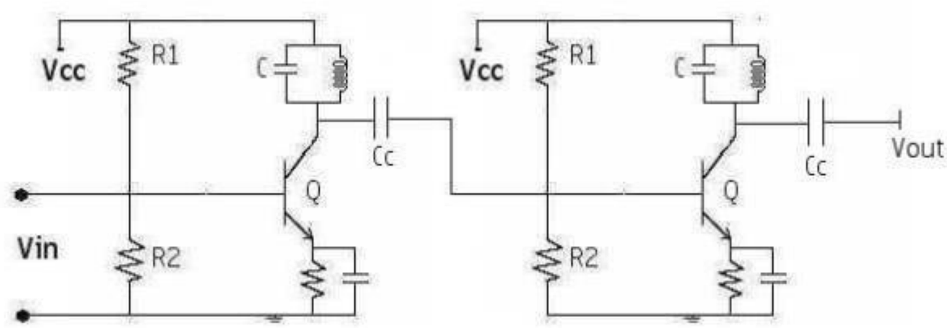


Overall response of synchronous amplifier



Comparison of single and synchronously tuned amplifier

Circuit diagram:



[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

Stagger Tuned Amplifiers are used to improve the overall frequency response of tuned Amplifiers. Stagger tuned Amplifiers are usually designed so that the overall response exhibits maximal flatness around the centre frequency. It needs a number of tuned circuits operating in union. The overall frequency response of a Stagger tuned amplifier is obtained by adding the individual response together.

Since the resonant Frequencies of different tuned circuits are displaced or staggered, they are referred as STAGGER TUNED AMPLIFIER.

The main advantage of stagger tuned amplifier is increased bandwidth. Its Drawback is Reduced Selectivity and critical tuning of many tank circuits. They are used in RF amplifier stage in Radio Receivers.

Analysis:

Gain of the single tuned amplifier:

$$\frac{A_v}{A_v\ (\text{at resonance})_1} = \frac{1}{1+j(X+1)}$$

$$\frac{A_v}{A_v\ (\text{at resonance})_2} = \frac{1}{1+j(X-1)}$$

where $X = 2\ Q_{eff}\ \delta$

Gain of the cascaded amplifier:

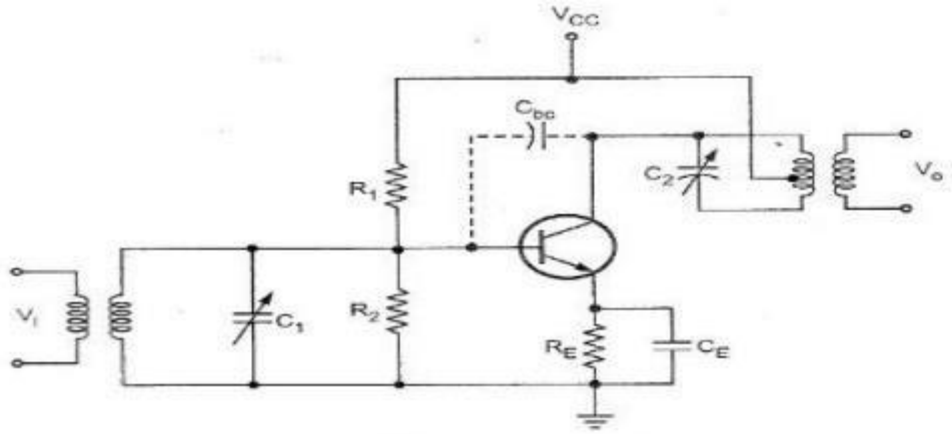
$$\frac{A_v}{A_v\ (\text{at resonance})_{cascaded}} = \frac{A_v}{A_v\ (\text{at resonance})_1} \times \frac{A_v}{A_v\ (\text{at resonance})_2}$$

$$\left|\frac{A_v}{A_v\ (\text{at resonance})}\right|_{cascaded} = \frac{1}{\sqrt{4+(2Q_{eff}\delta)^4}} = \frac{1}{\sqrt{4+16Q_{eff}^4\ \delta^4}}$$

$$= \frac{1}{2\sqrt{1+4Q_{eff}^4\ \delta^4}}$$

NEUTRALIZATION METHODS

In tuned RF amplifiers, transistor are used at the frequencies nearer to their unity gain bandwidths (i.e. f_T), to amplify a narrow band of high frequencies centred around a ratio frequency. At this frequency, the inter junction capacitance between base and collector, C_{bc} of the transistor becomes dominant, i.e., its reactance between low enough to be considered, which is otherwise infinite to be neglected as open circuit. Being CE configuration capacitance C_{be}, shown in the ig. 3.35 come across input and output circuits of an amplifier. As reactance of C_{bc} at RF is low enough it provide the feedback path from collector to base. With this circuit condition, if some feedback signal manages to reach the input from output in a positive manner with proper phase shift, then there is possibility of circuit converted to a positive manner with proper phase shift, then there is possibility of circuit converted to an unstable one, generating its own oscillations and can stop working as an amplifier. This circuit will always oscillate if enough energy is fed back from the collector to the base in the correct phase to overcome circuit losses. Unfortunately, the conditions for best gain and selectivity are also those which promote oscillation. In order to prevent oscillations in tuned RF amplifiers it was necessary to reduce the stage gain to a level that ensured circuit stability. This could be accomplished in several ways such as lowering the Q of tune circuits; stager tuning, losse coupling



[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

between the stages or inserting a 'loser' element into the circuit. While all these methods reduced gain, detuning and Q reduction had detrimental effects on selectivity. Instead of loosing the circuit performance to achieve stability, the professor L.A. Hazeltine introduced a circuit in which the troublesome effect o the collector to base capacitance of the transistor was neutralized by introducing a signal which cancels the signal coupled through the collector to base capacitance. He proved that the neutralization can be achieved by deliberately feeding back a portion of the output signal to the input in such a way that it has the same amplitude as the unwanted feedback but the opposite phase. Later on many neutralizing circuits were introduced. Let us study some of these circuits.

Hazeltine Neutralization

The ig. 3.36 shows one variation of the Hazeline circuit. In this circuit a small value of variable capacitance C_N is connected from the bottom of coil, point B, to the base. Therefore, the internal capacitance C_{bc}, shown dotted, feeds a signal from the top end of the coil, point A, to the transistor base and the C_N feeds a signal o equal magnitude but opposite polarity rom the bottom o coil, point B, to the base. The neutralizing capacitor, C_N can be adjusted correctly to completely nulliy the signal ed through the C_{bc}.

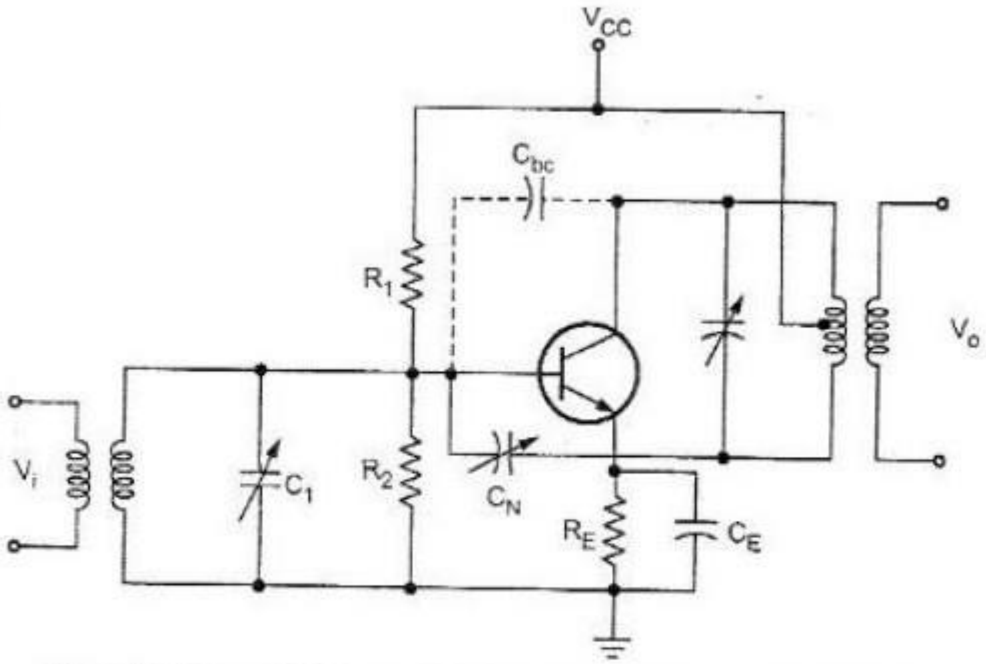


Fig. 3.36 Tuned RF amplifier with Hazeltine neutralization

[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

Neutralization using coil

The Fig. 3.38 shows the neutralization o RF amplifier using coil. In this circuit, L part of the tuned circuit at the base o next stage is oriented or minimum coupling to the other winding. It is wound on a separate from and is mounted at right angle to the coupled windings. If the windings are properly polarized, the voltage across L due to the circulating current in the base circuit will have the proper phase to cancel the signal coupled through the base to collector, C_{bc} capacitance.

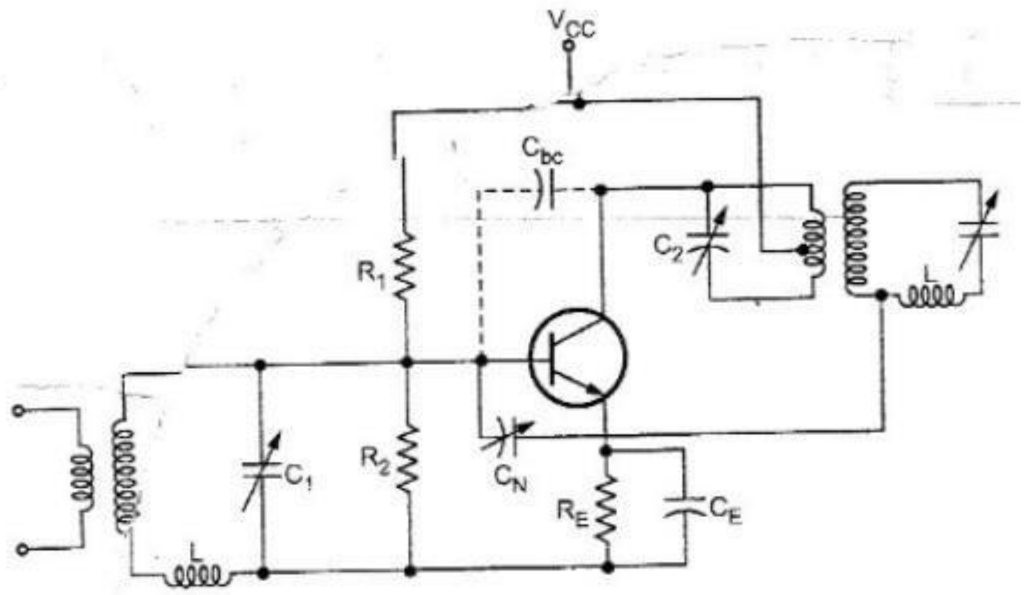


Fig. 3.38 Tuned RF amplifier using coil

[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

Important Short Questions and Answers

TUNED AMPLIFIERS

1. What is tuned amplifier? What are the various types of tuned amplifiers?

A tuned amplifier amplifies a certain range of frequencies (narrow band of frequencies) in the radio frequency region and rejects all other frequencies.

Types:

The various types of tuned amplifiers are

i) Single tuned amplifier
ii) Double tuned amplifier
iii) Stagger tuned amplifier & synchronously tuned amplifier.

2. Define tuned amplifier.

A tuned amplifier is defined as an amplifier circuit which amplifies a certain range of frequencies (narrow band of frequencies) in the radio frequency region and reject all other frequencies.

3. Why tuned amplifier cannot be used at low frequency?

For low frequencies the size L and C are large. So the circuit will be bulky and expensive, hence the tuned amplifiers cannot be used at low frequency.

4. What is the other name for tuned amplifier?

Tuned amplifiers used for amplifying narrow band of frequencies hence it si also known as “narrow band amplifier” or “Band pass amplifier”.

5. Mention The Two Applications of tuned amplifiers.

i) They are used in IF amplifiers in Radio and TV receivers.
ii) They are used in wireless communication systems.

6. State two advantages and two disadvantages of tuned amplifiers.

Advantages:

i) They amplify defined frequencies
ii) Signal to noise ratio (SNR) at output is good.
iii) They are suited for radio transmitters and receivers.

Disadvantages:

i) They are not suitable to amplify audio frequencies.
ii) Circuit is bulky and costly.
iii) The design is complex.

7. What is Single tuned and double tuned amplifier?

Single tuned amplifier:

A amplifier circuit that uses a single parallel tuned circuit as a load is called single tuned amplifier.

Double tuned amplifier:

The amplifiers having two parallel resonant circuit in its load are called double tuned amplifiers.

8. What are the advantages of double tuned amplifier over single tuned amplifier?

i) Provides higher gain
ii) Provides large 3dB bandwidth.
iii) Possess flatter response having steeper sides.

9. What are the different coil losses?

i) Hysteresis loss
ii) Copper loss
iii) Eddy current loss

10. What are the differences between single tuned and synchronously tuned amplifiers?

Single tuned amplifier	Synchronously tuned amplifier
• Uses one parallel tuned circuit as the load impedance and tuned to one frequency. • Hign gain and narrow bandwidth • Bandwidth is $BW = \frac{f_r}{Q}$	• Uses a number of identical cascaded single tuned stages tuned to same frequency. • Increases gain and reduces bandwidth. • The bandwidth equation is $BW_n = BW_1\sqrt{2^{1/n} - 1}$

11. What is Stagger tuned amplifier

If two or more tuned circuits which are cascaded are tuned to slightly different resonant frequencies, it is possible to obtain an increased bandwidth with a flat passbandwith steep sides. This technique is known as stagger tuning and the amplifier using this technique is called as stagger tuned amplifier.

12. What are the different types of neutralization?

i) Hazeltine neutralization
ii) Neutrodyne neutralization
iii) Rice neutralization

13. Why neutralization required in tuned amplifiers? & Draw the circuit for Narrow Band neutralization.

In order to prevent oscillations in tuned RF amplifiers it was necessary to reduce the stage gain to a level that ensured circuit stability. This can be accomplished in several ways such as lowering the Q of the tuned circuits, stagger tuning ,loose coupling between the stages. Instead of losingthe circuit performance to achieve stability, a circuitin which the troublesome effect of the collector to base capacitance of the transistor was neutralised by introducing a signal which cancels the signal coupled through the collector to base capacitance.

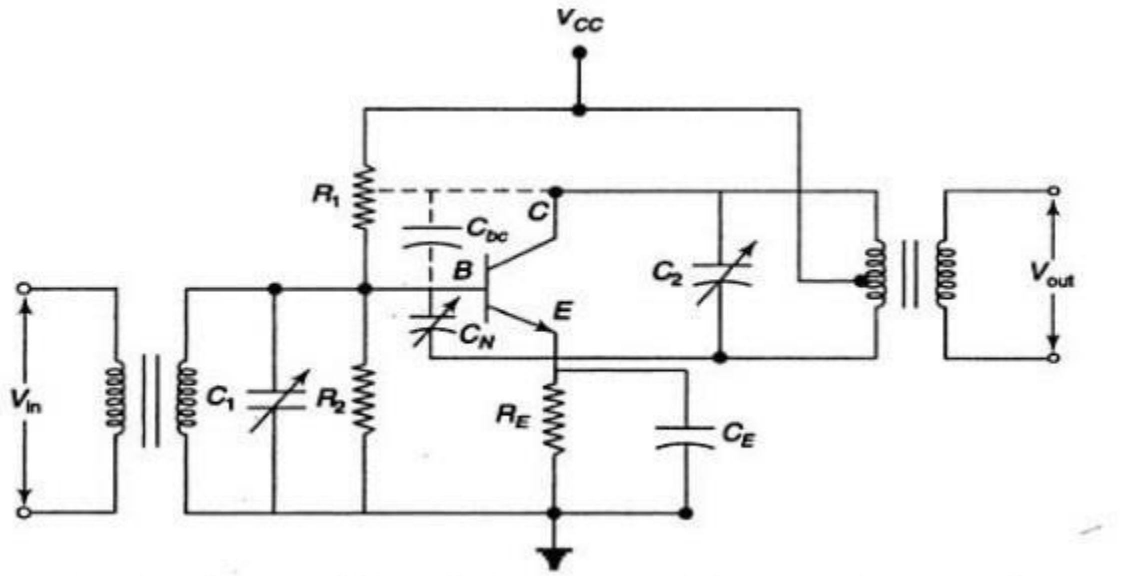


Fig. 13.30 Tuned RF amplifier with Hazeltine neutralization (C_N = neutralization capacitance)

[Source: Sedra and Smith, ―Micro Electronic Circuits‖; Sixth Edition, Oxford University Press]

14. Define loaded and unloaded Q.

Unloaded Q:

It is defined as the ratio of stored energy to dissipated energy in a reactor or resonator. For an inductor or capacitor

$$Q_u = \frac{X}{R_s}$$

Where X= reactance:

R_s= series resistance

Loaded Q:

The loaded Q or Q_L of a resonator is determined by how tightly the resonator is coupled to its terminations.

$$Q_L = 2\pi \times \frac{Maximum\ energy\ stored\ per\ cycle}{Energy\ dissipated\ per\ cycle + Energy\ dissipated\ due\ to\ external\ load}$$

15. What is the effect of cascading n stages of identical single tuned amplifiers (synchronously tuned) on the overall 3db bandwidth?

The bandwidth of n stage cascaded single tuned amplifier is given as

$$BW_n = BW_1\sqrt{2^{1/n} - 1}$$

From the above equation it is clear that the overall 3dB bandwidth reduces.

16. Mention the bandwidth of a double tuned amplifier

$$Bandwidth(\omega_2 - \omega_1) = \frac{\omega_0}{Q}\sqrt{(b^2 - 1) + 2b}$$

Where ω_0 is the resonance frequency in cycle/sec

Q is the Quality factor of the coil alone

b- is a constant

17. Where is the Q-point placed in a class C type amplifier? What are its applications?

In a class C type amplifier the Q-point is placed below the X-axis.

Applications:

- The Class C amplifiers are used to amplify the signals at radio frequencies.
- They are also used in mixer circuits.

18. Brief the relation between bandwidth and Q-factor.

The quality factor determines the 3dB bandwidth for the resonant circuit. The 3dB bandwidth for resonant circuit is given by

$BW = f_r/Q$
Where, f_r= centre frequency of a resonator
$BW = f_2 - f_1$

19. What is narrow band neutralization?

The process of cancelling the instability effect due to the collector to base capacitance of the transistor in tuned circuits by introducing a signal which cancels the signal coupled through the collector to base capacitance is called narrow band neutralization.

20. Mention two important features of stagger tuned amplifier.

i) It has better flat, wide band characteristics.
ii) Increased bandwidth

21. What is the need for neutralization circuits?

In tuned RF amplifiers, the inter-junction capacitance C_{bc} of the transistor becomes dominant (i.e) its reactance is low, it provides the feedback signal from collector to base. If some feedback signal manages to reach the input from output in a positive manner with proper phase shift, then amplifier keeps oscillating, thus stability of amplifier gets affected. Hence neutralization is employed.

22. Draw a class C tuned amplifier circuit and what is its efficiency.

$$\eta = \frac{P_{out}}{P_s} \times 100\%$$

At conduction angle $\theta = 180°$, $\eta = 78.5\%$

23. Derive the resonance frequency for the tank circuit shown:

At resonance $X_L = X_C$

$$2\pi f_r L = \frac{1}{2\pi f_r C}$$

Resonance frequency $f_r = \frac{1}{2\pi\sqrt{LC}}$

24. A tuned circuit has resonant frequency of 1600 KHz and bandwidth of 10 KHz. What is the value of its Q-factor?

25. A tuned amplifier has its maximum gain at a frequency of 2 MHz and has a bandwidth of 50 KHz.calculate the Q-factor.

26. An inductor of 250µH has Q=300 at 1MHz. Determine R_s and R_p of the inductor.

27. A parallel resonant circuit has an inductance of 150µH and a capacitance of 100pF. Find the resonant frequency.